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# Analysis of changes in the structure of rural household energy consumption in northern China: A case study

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**Abstract**

There is currently a paucity of research examining changes in the structure of household energy consumption in rural areas of northern China. Here, we thoroughly analyze household energy consumption in terms of energy sources and energy end-uses in villages of Huantai County from 1989 to 2005. Results indicated that commercial energy consumption increased, both in the absolute amount and the relative proportion. Non-commercial energy (traditional biomass energy) use decreased greatly but still accounted for a significant proportion of all energy sources. In terms of energy end-uses, cooking and home-heating energy consumptions were of nearly equal importance. While energy for cooking has historically dominated total consumption, energy used for recreational activities increased dramatically in comparison. In addition, we discuss the influence of changes in energy consumption structure on household energy expenditures, environmental effects and supply-demand balance of energy. Results showed the payout of household energy consumption was stable, the environment deteriorated, the fossil fuel supply was unsustainable in the long term. For the sustainable development of local energy sources, the environment, and the economy, it will be imperative to fully exploit suitable, local renewable energy resources.


*Keywords:* Energy consumption; Energy end-use types; Northern China; Renewable energy resources; Rural areas

**Contents**



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## 1. Introduction

With the rapid social and economic development as well as comprehensive rural energy construction since the reform and opening of China in 1978, the structure of household energy consumption has greatly improved in rural areas [1]. The ratio of commercial energy consumption to total energy consumption increased from 15.71% in 1980 to 45.04% in 2005. In addition, commercial energy consumption comprised an even higher proportion of total consumption in developed regions and northern China, where coal is used as the home-heating fuel [2,3]. The structure of rural household energy consumption varies in different stages and different regions and can be affected by many factors, including local energy resources, climate, economy, social structure, culture, and location [4,5]. However, certain aspects of consumption exhibit certain trends in similar regions. Therefore, the study of changes in the structure of energy consumption in representative regions is an important approach for understanding current energy consumption rates, developmental tendencies, and traits of rural household energy consumption in China.

Previous researches have begun to explore the changes in energy consumption in southern China [6–8], but quality data for northern China are lacking. There are clear differences in rural household energy consumption between the two regions. In northern China, large quantities of energy are consumed for home heating during cold periods, and the rural economy is relatively poor. To begin investigating energy issues in northern China, we used representative, prosperous rural villages of Huantai County for case studies of changes in the structure of rural household energy consumption (and related questions) from 1989 to 2005. Our final results are generalizable and can act as an important reference for other villages of northern China that are in the process of modernizing. Our findings are also important to further research into the balance of energy supply and demand, energy policy formation, and the rural eco-environment in northern China.

## 2. Description of Huantai County

Huantai County is located in the center of Shandong Province, which is part of the North China plain, at 36°51′–37°06′N and 117°50′–118°10′E. This region has a typical continental monsoon climate, characterized by an average annual temperature of 12.5 °C, with long and cold winters. This region is the primary food-producing area of China, earning the title "Granary of North Lu". Crops are dominated by a wheat–corn rotation pattern, and straw and stalk resources are abundant. Modern, intensive livestock breeding is also common, while the practice of sporadic, personal livestock breeding is diminishing. Both industry and agriculture have rapidly developed in recent years. The county-level economy reached 71st place in China's "100 powerful counties" in 2005. There are many employment opportunities for rural laborers, provided primarily by local town and village businesses and the construction industry. Rural per capita net annual income increased from 807 RMB (Chinese Yuan) in 1989 to 5540 RMB in 2005.

Huantai County was one of the six demonstration regions in the "China: Technical Assistance and Training in Integrated Rural Energy Planning" initiative sponsored by the Energy Sector Management Assistance Program (ESMAP), the Ministry of Agriculture of China (MOA), and the Ministry of Forestry of China (MOF). Huantai County also became one of the energy comprehensive construction counties in the eighth Five-Year period (1991–1995), and the straw gasification project was initially demonstrated there [9]. Local rural energy construction has achieved great progress.

## 3. Data and methods

All data concerning rural household energy consumption in Huantai County were collected from field surveys, which tend to be reliable and accurate. Data from 1989 were gathered with a cooperative sample survey and an on-the-spot investigation by the ESMAP, MOA, and MOF [10]. Data from 2005 were obtained using questionnaires in March and April 2006. We adopted a random stratified sampling method and distributed the questionnaires to 270 families. The respondents were househusbands or housewives. To better examine current rural household energy consumption in Huantai County, the 1987 questionnaire was altered slightly for use in 2005. A portion of the macrodata was collected from the Huantai Statistical Yearbooks and China Rural Energy Statistical Data in 1989 and 2005.

The consumption of commercial energy can be easily estimated and calculated in this region. However, the calculation of corn straw consumption was difficult due to the multiple usage strategies of different families, and the calculation results were significantly different using different conversion standards. Because corn straw consumption was high and occupied a relatively large proportion of total energy consumption, we used the dry weight of different corn straw parts for more accurate results at local. The

conversion coefficients are grain/corncob = 4.5, grain/stalk = 2.2, grain/stover (not including corncob) = 1.0, respectively.

## 4. Results and analysis

### 4.1. Increase in commercial energy use

The rural household per capita energy consumption of Huantai County increased from 483.84 kg of standard coal equivalent (kgce; 1 kgce = 7000 kcal) in 1989 to 543.43 kgce in 2005, with a yearly growth rate of only 0.77%. However, the consumption structure of energy sources changed greatly. Commercial energy consumption (except kerosene) increased, both in the absolute amount and the relative proportion (Table 1). The proportion of commercial energy use increased from 65.0% in 1989 to 82.75% in 2005. Coal consumption greatly surpassed other energy types, accounting for nearly 65.0% of total use in 2005. In addition, use of electricity, oil products, and liquefied petroleum gas (LPG) increased dramatically. These increases in energy consumption had two primary causes. First, many general lifestyle changes have taken place in recent years. For example, farmers' incomes are relatively high, increasing their ability to pay for energy use. In addition, the use of energy-consuming products such as household appliances has increased rapidly (Table 2), and recreational activities have become more common. Second, Huantai County is located in northern China, thus requiring large quantities of coal for home heating in winter.

Corn straw was the dominant form of non-commercial energy used at the local level. The per capita reduction of straw use was 75.70 kgce in the past 16 years but still accounted for 17.08% of total household energy consumption in 2005. Corn straw consumption remains important, because most families use corncobs as fuel. In addition, some relatively poor families' cooking energy consumption still depends on straw. Results also indicated that in 2005, 11.11% of households did not use traditional biomass energy at all, 37.04% of households used corn stover, and 87.04% of households still used corncobs. The per capita corncob consumption was 60.53 kgce in 2005, which accounted for 65.22% of total straw consumption. Firewood consumption accounted for a small proportion of total energy consumption in the two different years due to a scarcity of resources. In addition, the use of biogas decreased and nearly disappeared.

### 4.2. Energy end-use types improve the quality of life

The energy end-uses of a rural household refer to energy consumption for activities such as cooking, home heating, refrigeration, lighting, recreation, private vehicle use, and livestock breeding, all of which satisfy farmers' basic living requirements and improve the quality of life. Here, we focus on the most important energy end-use types for these rural areas of northern China, including cooking, lighting, home heating, recreation, and livestock breeding. The structure of energy consumption for different end-use types also changed greatly in the past 16 years (Table 3). Cooking dominated in 1989, but currently cooking and home heating are of equal importance. By 2005, there was a rapid increase in recreational activities, stable growth of lighting, and a disappearance of livestock breeding (Fig. 1).

#### 4.2.1. Cooking energy consumption

Rural household per capita cooking energy consumption decreased greatly, from 300.22 kgce in 1989 to 237.29 kgce in 2005. The energy types used included coal, straw, LPG, and electricity. Coal consumption exceeded that of straw, becoming the most important energy source and accounting for 51.89% of total cooking energy consumption. On the whole, cooking energy consumption depended on coal during the home-heating season. Straw consumption decreased 42.02% in the past 16 years, but accounted for

Table 1
Per capita rural household energy consumption of different energy types (kgce)

| Year | Electricity | LPG | Straw | Firewood | Coal | Oil products | Kerosene | Biogas | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1989 | 15.02 (3.10%) | 3.81 (0.79%) | 168.51 (34.83%) | 0.09 (0.02%) | 295.02 (60.97%) | 0 (0) | 0.69 (0.14%) | 0.70 (0.15%) | 483.84 (100%) |
| 2005 | 54.34 (10.00%) | 16.19 (2.98%) | 92.81 (17.08%) | 0.93 (0.17%) | 352.82 (64.92%) | 26.34 (4.85%) | 0 (0) | 0 (0) | 543.43 (100%) |

Table 2
Quantity of primary energy-consuming appliances per 100 rural households in 1989 and 2005

| Year | Amounts of main household energy-consuming appliances (per 100 households) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Washing machine | Refrigerator | Color TV | Electrical fan | Air conditioner | Motorcycle | Motor bicycle | LPG cooker | Electrical cooker | Household central heating stove |
| 1989 | 11 | 0 | 10 | 75 | 0 | 1 | 0 | 24 | – | – |
| 2005 | 79 | 48 | 116 | 224 | 22 | 57 | 15 | 86 | 60 | 74 |

Table 3
Structure of per capita rural household energy consumption in 1989 and 2005 (kgce)

| Year | | Straw | Firewood | Biogas | Coal | Electricity | Oil products | LPG | Kerosene | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1989 | Cooking | 160.08 | 0.09 | 0.40 | 135.84 | – | – | 3.81 | – | 300.22 |
| | Home heating | 3.15 | – | – | 159.15 | – | – | – | – | 162.30 |
| | Recreation | – | – | – | – | 3.71 | | – | – | 3.70 |
| | Lighting | – | – | 0.10 | – | 11.31 | – | – | 0.69 | 12.10 |
| | Livestock breeding | 5.28 | – | 0.20 | – | – | – | – | – | 5.48 |
| 2005 | Cooking | 92.81 | 0.93 | – | 123.12 | 4.24 | – | 16.19 | – | 237.29 |
| | Home heating | – | – | – | 229.70 | – | – | – | – | 229.70 |
| | Recreation | – | – | – | – | 30.71 | 26.34 | – | – | 57.05 |
| | Lighting | – | – | – | – | 19.39 | – | – | – | 19.39 |
| | Livestock breeding | – | – | – | – | – | – | – | – | – |

*Notes*: Electricity for home heating is incorporated into recreational energy consumption; coal for home heating is separated from recreational energy consumption; rural household energy consumption does not include energy for intensive livestock farms; recreational energy consumption includes energy for refrigeration, entertainment, and private vehicle use.

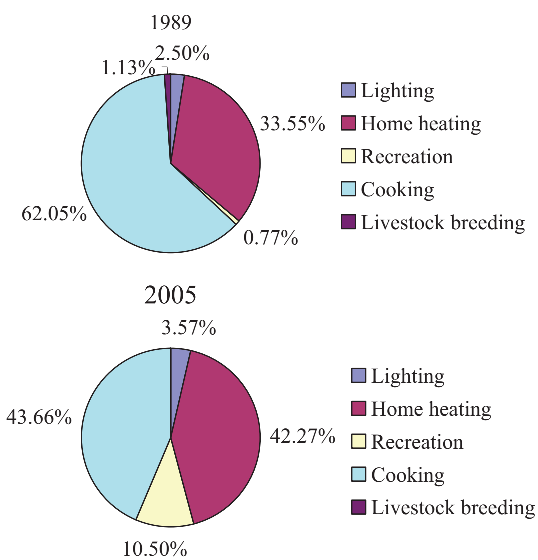



Fig. 1. Structure of per capita energy end-use types in 1989 and 2005.

nearly 40.0% of total cooking consumption in 2005. In the non-heating season, straw was primarily substituted with high-quality commercial energy; thus, the consumption of LPG and electricity for cooking increased dramatically.

In these rural areas of Huantai County, the energy utilization efficiency of straw and firewood burning was 18.0% (1989) and 20.0% (2005), respectively. The energy utilization efficiency of coal was 22.0% (1989) and 25.0% (2005), and the thermal conversion rates of LPG and biogas were 60.0% and 50.0%, respectively. Thus, per capita effective cooking energy consumption was 61.20 kgce in 1989 and 63.48 kgce in 2005, exhibiting no decrease with the reduction of overall energy consumption. These results indicate that the effective energy demand for cooking did not significantly change with the rise in standard of living. The optimization of the structure of household cooking energy consumption increased energy utilization efficiency, which in turn improved the farmers' quality of life and saved a large quantity of straw.

#### 4.2.2. Home-heating energy consumption

Energy consumption for home heating is an important indicator of the rural standard of living in northern China. Energy sources used for home heating were initially dominated by traditional biomass energy such as straw and firewood, and then gradually shifted to domination by coal. Coal was already the primary energy source for home heating at local in 1989. However, heating elements were primarily single coal stoves with a small heating area and low heating efficiency. As the number of heating elements increased in the marketplace, various large-diameter energy-saving coal stoves with radiator heating became the primary sources for home heating. These larger stoves consumed more coal per unit time and provided more heating area than single coal stoves. Per capita heating energy consumption was 250.70 kgce with radiator heat, which was 1.46 times that of households with a single coal stove. In 2005, 74 out of 100 families used radiator heat, whereas this heat source was seldom used by farmers in 1989. With this shift in heating source, the per capita heating area increased from 7.14 to 16.17 $m^2$, and heating time also increased. As a result, per capita coal consumption for home heating increased from 159.18 kgce in 1989 to 229.70 kgce in 2005.

#### 4.2.3. Recreational energy consumption

Energy consumption for entertainment and recreational activities refers to energy consumed for improving the quality of life and includes the use of items such as private vehicles, color TVs, washing machines, refrigerators, air conditioners, and motorcycles. In the past, such household appliances were usually only found in urban residences, but now many are currently used by common rural families. For example, 48.0% of the households studied in 2005 owned refrigerators and 22.0% owned air conditioners; however, no families had such appliances in 1989. In addition, the proportion of households owning motorcycles increased from 1.0% in 1989 to 57.0% in 2005, and even very few affluent families currently own private cars. As a result of these increases in

appliance ownership, the per capita recreational energy consumption increased dramatically from 3.71 kgce in 1989 to 57.05 kgce in 2005. Energy sources for such recreational activities have shifted from a small amount of electricity use to larger amounts of electricity and oil products.

#### *4.2.4. Lighting energy consumption*

After rural power network reconstruction, the supply of electricity became more stable. Current lighting energy consumption relies almost completely on electricity, while kerosene and biogas use have diminished greatly. The per capita electricity consumption increased from 11.31 kgce in 1989 to 19.39 kgce in 2005, likely caused by more electric lights left on longer. However, light bulb use and lighting time are both limited, thus the increase of lighting energy consumption was not as drastic as for other energy end-uses.

#### *4.2.5. Livestock breeding energy consumption*

Energy consumption for breeding livestock only includes energy used for a family's personal livestock, not the energy used for intensive livestock farms (>10 pig equivalents). Livestock breeding energy consumption decreased, primarily because personal livestock breeding reaps low economic benefits and is restricted by residential area. Personal livestock breeding essentially disappeared in Huantai County. In addition, the development of household biogas digesters in China often depended on a stable supply of animal wastes. Thus, the reduction in livestock breeding energy consumption serves as a local indicator of the disappearance of household biogas digesters.

## 5. Discussion of changes in the structure of rural household energy consumption

### *5.1. Stable payout of rural household energy expenditure*

Household energy expenditure is an important component of a family's total living expenditures. Because there is no market for traditional biomass resources and farmers use them locally for free, energy expenditure only includes commercial energy sources. Per capita annual energy expenditure increased from 73.5 RMB in 1989 to 530.0 RMB in 2005, accounting for 9.11% and 9.57% of net income, respectively (Table 4). These results indicate that the ratio of energy expense to net income has remained relatively stable, which is consistent with data from southern China [7]. However, the ratio in Huantai County is clearly higher than that in southern China, primarily because of the large amount of coal consumption used for home heating in northern China. Farmers often consciously regulate their consumption of different commercial energy sources according to their income and the utility of different energy sources. Such practices must be taken into account when developing markets for rural energy products and devising plans for rural energy supply and demand that may include renewable commercial energy sources.

### *5.2. Environmental deterioration*

The proportion of traditional biomass energy used was much lower in Huantai County than in rural areas of the country as a whole. Reserved wheat straw was often returned to the fields, which increased soil organic matter content and reduced emissions of greenhouse gases (GHGs) [11]. However, corn straw is difficult to return to the fields because of technology and cost constraints. Most corn straw was burned in the fields during harvest, and in the process, so was much of the undecomposed wheat straw. These practices resulted in the waste of resources, environmental pollution, and the obstruction of normal traffic. Coal was also burned directly, which not only emitted GHGs and environmental pollutants such as $SO_2$, CO, total suspended particulates (TSP), but also detrimentally affected indoor environments and residents' health.

Here, we use $CO_2$ and $SO_2$ emissions as examples. The conversion standards of $CO_2$ and $SO_2$ from the burning of different energy sources are based on the methods of Wang and Tian [12,13]. The per capita emission quantity of $CO_2$ and $SO_2$ in 1989 and 2005 are presented in Tables 5 and 6, respectively. The growth rate of $CO_2$ emissions was 0.38% per year. While $CO_2$ emissions from commercial energy sources increased rapidly, the emissions in 2005 were 1.41 times than that in 1989. Considering most straw resource was burned in fields, $CO_2$ emissions of the regional system increased greatly due to changes in rural household energy consumption. $SO_2$ emissions resulted primarily from the

Table 4
Per capita cash expenses of commercial energy consumption

| Year | | Electricity | LPG | Kerosene | Coal | Oil products[a] | Total |
|---|---|---|---|---|---|---|---|
| 1989 | Energy consumption (kgce) | 15.02 | 3.81 | 0.69 | 295.02 | – | – |
| | Price (RMB/kgce) | 0.97 | 0.67 | 0.48 | 0.19 | 1.50 | – |
| | Cash expense (RMB) | 14.57 | 2.55 | 0.33 | 56.05 | – | 73.50 |
| 2005 | Energy consumption (kgce) | 54.34 | 16.19 | 0 | 352.82 | 26.34 | – |
| | Price (RMB/kgce) | 1.34 | 2.80 | 0 | 0.87 | 3.99 | – |
| | Cash expense (RMB) | 72.63 | 45.33 | 0 | 306.95 | 105.09 | 530.00 |

[a]Oil products only include gasoline and diesel oil that are consumed by private motorcycles and cars.

Table 5
Per capita $CO_2$ emissions from various energy sources (kg)

| Year | Emission quantity of $CO_2$ | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Straw | Firewood | Biogas | Electricity | LPG | Kerosene | Coal | Oil products | |
| 1989 | 452.6 | 0.27 | 1.06 | 27.14 | 6.9 | 1.34 | 614.16 | 0 | 1103.47 |
| 2005 | 249.28 | 2.84 | 0 | 98.15 | 26.39 | 0 | 743.49 | 50.03 | 1170.18 |

Table 6
Per capita $SO_2$ emissions from various energy sources (kg)

| Year | Emission quantity of $SO_2$ | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Straw | Firewood | Biogas | Electricity | LPG | Kerosene | Coal | Oil products | |
| 1989 | 0.19 | <0.01 | <0.01 | 0.30 | 0.03 | 0.01 | 5.53 | 0 | 6.06 |
| 2005 | 0.11 | <0.01 | 0 | 1.07 | 0.11 | 0 | 6.62 | 0.21 | 8.12 |

burning of fossil fuels (especially coal) and increased greatly with the increase in daily fossil fuel consumption.

### *5.3. Unsustainability of fossil fuel supply*

China has abundant coal resources but serious shortages of oil and gas. According to statistics from 2002, the per capita mineable reserves of oil, natural gas, and coal were 1.95 t, 1176 $m^3$, and 89 t, respectively, equal to 8.49%, 4.69%, and 55.98% of average global levels [14]. Among the limited fossil fuels supplied in the marketplace, the energy resources distributed for daily rural life are much smaller. The rural household per capita consumption of oil products, LPG, coal, and electricity were 19.01, 5.51, 261.44, and 39.35 kgce, respectively, in northern China in 2005, which is equivalent to 72.17%, 34.03%, 74.10%, and 72.41% of the corresponding total consumption in Huantai County in the same year. If the standard of living increases in China as projected by the government, in 2020, the demand for high-quality energy sources in farmers' daily lives will also have to be increased greatly. If the level of rural household per capita energy consumption in northern China reaches or surpasses that of Huantai County in the near future, the fossil fuels supplied to rural markets will not satisfy farmers' requirements in the long term.

### *5.4. Development of suitable renewable energy resources*

In terms of environmental effects and energy supply, the current energy consumption structure in rural areas of Huantai County is unsustainable. To ameliorate the situation, energy consumption must be properly regulated. New regulations should consider the important features of rural household energy consumption, such as feasibility, structure, substitution of renewable sources for fossil fuels, source variability, symbolization of life quality [7], and integrating traditional, local energy sources. In addition, regulations should fully exploit local high-quality renewable energy sources, such as modern biomass and solar energy to guarantee the effective supply of commercial energy.

Research and development of biomass energy sources are rapidly increasing in China. The primary sources for modern biomass energy used by farmers include biogas, straw gasification fuel, and straw briquettes. There are abundant straw resources at the local level even if all wheat straw is returned to the fields as organic fertilizer. For example, the per capita amount of available corn straw was 795.41 kg in 2005. In addition, several techniques for using biomass energy have already been developed [15,16] and are economically competitive with fossil fuel energy [17–19]. According to previous studies and experiences in the field [9,20], the techniques suitable at the local level include large/medium-scale biogas plants, straw gasification for heat, gas, and power cogeneration, and straw briquettes. However, household biogas digesters should only be cautiously developed in such villages, because, according to our survey, only a small percentage (8.89%) of rural households were potentially willing to develop this type of energy source. Solar energy can be also incorporated into daily life by constructing energy-saving eco-buildings and through the general use of solar water heaters. If modern biomass energy and solar energy can partially replace traditional biomass energy and fossil fuels for daily energy end-uses, the structure of regional energy consumption will be optimized, environmental quality will greatly improve, and farmers' standards of living will significantly increase.

## 6. Conclusions

With the rapid economic development in rural areas of Huantai County in the past 16 years, the ratio of commercial to household energy consumption increased 17.75%. Per capita increment of coal consumption was 57.80 kgce, due primarily to home heating. Coal consumption was much higher than any other energy type and accounted for 64.92% of all household energy consumption. In addition, the consumptions of electricity, oil

products, and LPG increased dramatically for recreational activities and cooking. Traditional biomass energy consumption decreased greatly, but still accounted for 17.25% of all household energy consumption. The structure of energy consumption for different energy end-use types also exhibited significant shifts over the 16-year study period. For example, energy for home heating and recreation increased rapidly, which improved farmers' quality of life. While energy consumed for cooking dominated total energy consumption in the past, our study demonstrated that cooking and home-heating energy consumption currently have nearly equal importance.

Rural household energy consumption in Huantai County primarily depended on fossil fuel energy (especially coal), which is unsustainable due to environmental effects and energy supply constraints. In addition, low-efficiency traditional biomass energy was used for cooking, and straw was often burned directly or indirectly in the fields. These practices wasted resources and polluted both indoor and outdoor environments. Instead, China should fully develop and utilize modern biomass energy and solar energy to sustainably develop energy sources, the environment, and the economy.

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